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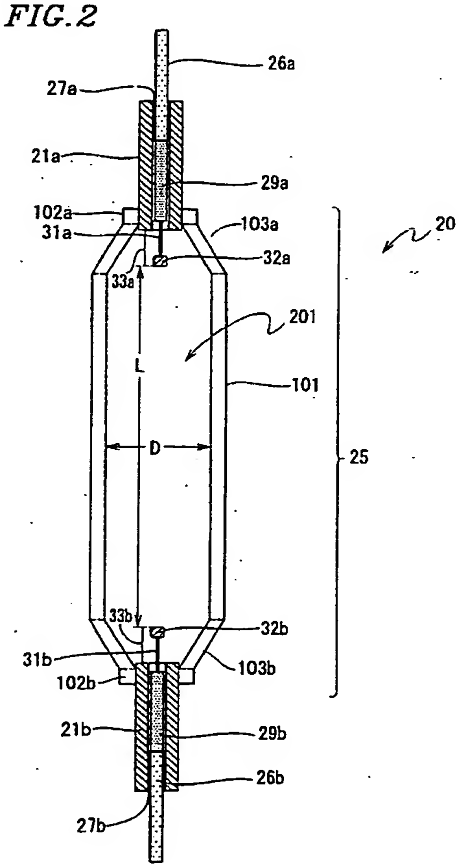
(54) Metal halide lamp and lighting system

(57) A metal halide lamp (10) comprises: a discharge chamber (20) having a light-transmissive chamber wall structure (25) which defines a discharge region (20), a first electrode, and a second electrode, the first and second electrodes being positioned opposite to each other; and an ionizable material contained in the discharge region (20), the ionizable material including mercury, rare gas, and at least two types of halides which includes praseodymium halide and sodium halide, wherein a diameter D of the chamber wall structure (25) and an electrode separation distance L between the first and second electrodes cross each other substantially at right angles and satisfy the relationship of L/D>4.

FIG. 2



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Description

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION:

[0001] This invention relates to high intensity arc discharge lamps and more particularly to dimmable high intensity arc discharge metal halide lamps having high efficacy.

2. DESCRIPTION OF THE RELATED ART:

[0002] Due to the ever-increasing need for energy conserving lighting systems that are used for interior and exterior lighting, lamps with increasing lamp efficacy are being developed for general lighting applications. Thus, for instance, electrodeless fluorescent lamps have been recently introduced in markets for indoor, outdoor, industrial, and commercial applications. An advantage of such electrodeless lamps is the removal of internal electrodes and heating filaments that are a life-limiting factor of conventional fluorescent lamps. However, electrodeless lamp systems are much more expensive because of the need for a radio frequency power system which leads to a larger and more complex lamp fixture design to accommodate the radio frequency coil with the lamp and electromagnetic interference with other electronic instruments along with difficult starting conditions thereby requiring additional circuitry arrangements.

[0003] Another kind of high efficacy lamp is the arc discharge metal halide lamp that is being more and more widely used for interior and exterior lighting. Such lamps are well known and include a light-transmissive arc discharge chamber sealed about an enclosed a pair of spaced apart electrodes and typically further contain suitable active materials such as an inert starting gas and one or more ionizable metals or metal halides in specified molar ratios, or both. They can be relatively low power lamps operated in standard alternating current light sockets at the usual 120 Volts rms potential with a ballast circuit, either magnetic or electronic, to provide a starting vol tage and current limiting during subsequent operation.

[0004] Such lamps may have a ceramic material arc discharge chamber that usually contains quantities of NaI, TlI and rare earth halides such as DyI_3, HoI_3, and TmI_3 along with mercury to provide an adequate voltage drop or loading between the electrodes. Lamps containing those materials have good performance on Correlated Color Temperature (CCT), Color Rendering Index (CRI), and a relatively high efficacy up to 95 lumens-per-watt (LPW). In a conventional metal halide lamp, an arc discharge chamber includes CeI_3 and NaI, whereby high efficacy is achieved (see, for example, U.S. Patent No. 5,973,453). In another conventional metal halide lamp, an arc discharge chamber includes sodium iodide along with mercury, whereby high efficacy is achieved (see, for example, U.S. Patent No. 6,300,729). Of course, to further save electric energy in lighting by using more efficient lamps, high intensity arc discharge metal halide lamps with even higher lamp efficacies are needed. More electric energy can be saved by dimming such lamps in use when full light output is not needed through reducing the electrical current therethrough, and so high intensity arc discharge metal halide lamps with good performance under such dimming conditions are desirable for many lighting applications.

[0005] However, under these dimming conditions when lamp power is reduced to about 50% of rated value, such ceramic material chamber arc discharge metal halide lamps radiate light in which the color rendering index decreases significantly through having a strong green hue due to relatively strong Tl radiation.

SUMMARY OF THE INVENTION

[0006] According to one aspect of the present invention, there is provided a metal halide lamp, including: a discharge chamber having a light-transmissive chamber wall structure which defines a discharge region, a first electrode, and a second electrode, the first and second electrodes being positioned opposite to each other; and an ionizable material contained in the discharge region, the ionizable material including mercury, rare gas, and at least two types of halides which includes praseodymium halide and sodium halide, wherein a diameter D of the chamber wall structure and an electrode separation distance L between the first and second electrodes cross each other substantially at right angles, and satisfy the relationship of $L/D>4$.

[0007] In one embodiment of the invention, the chamber wall structure is formed of polycrystalline alumina.

[0008] In another embodiment of the invention, the praseodymium halide is praseodymium iodide (PrI_3), and the sodium halide is sodium iodide (NaI).

[0009] In still another embodiment of the invention, the chamber wall structure has a first end positioned at the first electrode side and a second end positioned at the second electrode side, and the first end and the second end are tapered.

[0010] In still another embodiment of the invention, the discharge chamber further includes a thermal shield which

covers at least one of the first end and the second end.

[0011] In still another embodiment of the invention, the rare gas is selected from a group consisting of xenon (Xe), argon (Ar), neon (Ne), and krypton (Kr).

[0012] In still another embodiment of the invention, the diameter D and the electrode separation distance L satisfy the relationship of $7 \leq L/D \leq 9$.

[0013] In still another embodiment of the invention, the ratio of the amount of mercury to the volume of the discharge region is equal to or smaller than 4 mg/cm^3.

[0014] In still another embodiment of the invention, the ionizable material further includes cerium halide.

[0015] In still another embodiment of the invention, the metal halide lamp further includes: a light-transmissive bulbous envelope; and a base connected to the envelope, the base having a first access wire and a second access wire extending into the envelope, wherein the discharge chamber is placed in the envelope, the first electrode is connected to the first access wire, and the second electrode is connected to the second access wire.

[0016] In still another embodiment of the invention, the praseodymium halide is praseodymium iodide (PrI_3), and the sodium halide is sodium iodide (NaI).

[0017] In still another embodiment of the invention, the praseodymium halide is praseodymium iodide (PrI_3), and the sodium halide is sodium iodide (NaI).

[0018] In still another embodiment of the invention, the praseodymium halide is praseodymium iodide (PrI_3), and the sodium halide is sodium iodide (NaI).

[0019] According to another aspect of the present invention, there is provided a lighting system including a metal halide lamp and an operation circuit for allowing the metal halide lamp to operate, the metal halide lamp including: a discharge chamber having a light-transmissive chamber wall structure which defines a discharge region, a first electrode, and a second electrode, the first and second electrodes being positioned opposite to each other; and an ionizable material contained in the discharge region, the ionizable material including mercury, rare gas, and at least two types of halides which includes praseodymium halide and sodium halide, wherein a diameter D of the chamber wall structure and an electrode separation distance L between the first and second electrodes cross each other substantially at right angles, and satisfy the relationship of $L/D>4$, and the operation circuit being constructed so as to supply the metal halide lamp with an electric voltage for allowing the metal halide lamp to start and discharge, and to supply the metal halide lamp with an electric current for adjusting an operation power of the metal halide lamp.

[0020] In one embodiment of the invention, the ratio of the amount of mercury to the volume of the discharge region is equal to or smaller than 4 mg/cm^3.

[0021] Thus, the invention described herein makes possible the advantages of providing: (1) arc discharge metal halide lamps having higher efficacies and better color performance under dimming conditions; and (2) a lighting system using such an arc discharge metal halide lamp.

[0022] These and other advantages of the present invention will become apparent to those skilled in the art upon reading and understanding the following detailed description with reference to the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023]

Figure **1** is a side view, partially in cross section, of an arc discharge metal halide lamp of the present invention having a configuration of a ceramic arc discharge chamber therein.

Figure **2** shows the arc discharge chamber of Figure **1** in cross section in an expanded view.

Figure **3** is a graph showing the relationship between the lamp efficacy (LPW) and the discharge chamber effective diameter for typical lamps of the present invention.

Figure **4** is a graph showing the relationship between the lamp efficacy (LPW) and the ratios of arc discharge chamber electrode separation length to effective diameter for typical lamps of the present invention.

Figure **5** is a graph showing the relationship between the lamp efficacy (LPW) and the ratios of arc discharge power to effective diameter for typical lamps of the present invention.

Figures **6A** through **6G** show alternative embodiments for the arc discharge chamber of Figure **1** in cross section views.

Figure **7** shows the Correlated Color Temperature (CCT) changes for typical lamps of the present invention using

alternative molar ratios of PrI_3 and NaI as active materials therein for dimming from 150 W to 75 W.

Figure **8** shows the lamp efficacy (LPW) changes for typical lamps of the present invention using alternative molar ratios of PrI_3 and NaI as active materials therein for dimming from 150 W to 75 W.

Figure **9** shows the Color Rendering Index (CRI) changes for typical lamps of the present invention using alternative molar ratios of PrI_3 and NaI as active materials therein for dimming from 150 W to 75 W.

Figure **10** shows the relationship between the lamp efficacy (LPW) and the mercury dose per unit discharge chamber volume for typical lamps of the present invention.

Figure **11** is a block diagram showing an electronic ballast circuit in a lamp of the present invention.

Figure **12** is a circuitry diagram of the electronic ballast circuit of Figure **11**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0024] Hereinafter, embodiments of the present invention will be described with reference to the drawings.

[0025] Referring to Figure **1**, an arc discharge metal halide lamp, **10**, is shown in a partial cross section view having a bulbous borosilicate glass envelope, **11**, partially cut away in this view, fitted into a conventional Edison-type metal base, **12**. The glass envelope **11** is transparent. Lead-in electrode wires (first and second access wires), **14** and **15**, of nickel or soft steel each extend from a corresponding one of the two electrically isolated electrode metal portions in base **12** parallely through and past a borosilicate glass flare (envelope length axis past flare), **16**, positioned at the location of base **12** and extending into the interior of envelope **11** along the axis of the major length extent of that envelope (along the broken line **104** of Figure **1**). The first access wire **14** and second access wire **15** extend initially on either side of, and in a direction parallel to, the envelope length axis past flare **16** to have portions thereof located further into the interior of envelope **11**. Some remaining portion of each of the first access wire **14** and second access wire **15** in the interior of envelope **11** are bent at acute angles away from this initial direction after which the bent first access wire **14** ends following some further extending thereof to result in it more or less crossing the envelope length axis **104**.

[0026] The second access wire **15**, however, with the first bend therein past flare **16** directing it away from the envelope length axis **104,** is bent again at a portion **15a** of Figure **1** to have the next portion thereof extend substantially parallel that axis **104**, and further bent again at a portion **15b** of Figure **1** at a right angle to have the succeeding portion thereof extend substantially perpendicular to, and more or less cross the envelope length axis **104** near the other end of envelope **11** opposite that end thereof fitted into base **12.** The portion of the second access wire **15** parallel to the envelope length axis **104** passes through an aluminum oxide ceramic tube, **18,** to prevent the production of photoelectrons from the surface of the second access wire **15** during operation of the lamp, and also supports a conventional getter, **19**, to capture gaseous impurities. A further two right angle bends in the second access wire **15** (at portions **15c** and **15d**) places a short remaining end portion of that wire below and parallel to the portion thereof originally described as crossing the envelope length axis **104** which short end portion is finally anchored at this far end of envelope **11** from base **12** in a borosilicate glass dimple **24.**

[0027] A ceramic arc discharge chamber, **20,** configured about a contained region as a shell structure having polycrystalline alumina walls that are translucent to visible light, is shown in one possible configuration in Figure **1**. Chamber **20** has a chamber wall structure **25** and a pair of small inner and outer diameter ceramic truncated cylindrical shell portions **21a** and **21b** (or tubes **21a** and **21b**) that are shrink fitted into a corresponding one of the two open ends of the chamber wall structure **25.** In this specification, the tubes **21a** and **21b** cover first and second electrodes (described later) so as to shut off heat, i.e., the tubes **21a** and **21b** function as first and second thermal shields, respectively.

[0028] The chamber wall structure **25** has a larger diameter truncated cylindrical shell portion **101** between the ends of the chamber **20** and a very short extent smaller diameter truncated cylindrical shell portions **102a** and **102b** at respective ends with a partial conical shell portion **103a** and **103b** there joining the smaller diameter truncated cylindrical shell portions **102a** and **102b** there to the larger diameter truncated cylindrical shell portion **101**.

[0029] In this specification, the smaller diameter truncated cylindrical shell portion **102**a and the conical shell portion **103a** are integrally referred to as a first end. Similarly, the smaller diameter truncated cylindrical shell portion **102b** and the conical shell portion **103b** are integrally referred to as a second end. The first end is tapered from the conical shell portion **103a** toward the smaller diameter truncated cylindrical shell portion **102a**. Similarly, the second end is tapered from the conical shell portion **103b** toward the smaller diameter truncated cylindrical shell portion **102b**. The first and second ends are positioned opposite to each other. The first end is positioned at a first electrode side, while the second end is positioned at a second electrode side. The first and second electrodes will be described later.

[0030] The chamber **20** may also have first and second thermal shields (not shown) for shielding heat. The first thermal shield covers at least one of the smaller diameter truncated cylindrical shell portion **102a**, the conical shell portion **103a**, and the tube **21a**. The first thermal shield preferably covers the first end (i.e., the smaller diameter truncated cylindrical shell portion **102a** and the conical shell portion **103a**). Similarly, the second thermal shield covers at least one of the smaller diameter truncated cylindrical shell portion **102b**, the conical shell portion **103b**, and the tube **21b**. The second thermal shield preferably covers the second end (i.e., the smaller diameter truncated cylindrical shell portion **102b** and the conical shellportion **103b**). Alternatively, the chamber **20** may have only one of the first and second thermal shields.

[0031] Chamber electrode interconnection wires, **26a** and **26b**, of niobium each extend out of a corresponding one of tubes **21a** and **21b** to reach and be attached by welding to, respectively, the first access wire **14** at its end portion crossing the envelope length axis **104** and to the second access wire **15** at its portion originally described as crossing the envelope length axis **104**. This arrangement results in chamber **20** being positioned and supported between these portions of the first and second access wires **14** and **15** so that its long dimension axis approximately coincides with the envelope length axis **104**, and further allows electrical power to be provided therethrough to chamber **20**.

[0032] Figure **2** is a cross section view of arc discharge chamber **20** of Figure **1** showing the discharge region **201** therein contained within its bounding walls that are defined by the chamber wall structure **25** and tubes **21a** and **21b**. In Figure **2**, like elements are indicated by like reference numerals used in Figure **1**, and detailed descriptions thereof are omitted.

[0033] The discharge region **201** is supplied with an ionizable material. Such an ionizable material includes mercury, rare gas, and a halide. The rare gas is selected from a group consisting of xenon (Xe), argon (Ar), neon (Ne), and krypton (Kr). The halide includes at least praseodymium halide and sodium halide.

[0034] Chamber electrode interconnection wire **26a**, being of niobium, has a thermal expansion characteristic that relatively closely matches that of tube **21a** and that of a glass frit, **27a**, affixing wire **26a** to the inner surface of tube **21a** (and hermetically sealing that interconnection wire opening with wire **26a** passing therethrough) but cannot withstand the resulting chemical attack resulting in the forming of a plasma in the discharge region **201** of chamber **20** during operation. Thus, one end of molybdenum lead-through wire, **29a**, which can withstand operation in the plasma, is connected to one end of interconnection wires **26a** by welding, and other end of lead-through-wire **29a** is connected to one end of a tungsten main electrode shaft, **31a**, by welding.

[0035] In addition, a tungsten electrode coil, **32a**, is integrated and mounted to the tip portion of the other end of the main electrode shaft **31a** by welding, so that electrode **33a** is configured by main electrode shaft **31a** and electrode coil **32a**. Electrode **33a** is formed of tungsten for good thermoionic emission of electrons while withstanding relativelywell the chemical attack of the metal halide plasma. Lead-through wire **29a** serves to dispose electrode **33a** at a predetermined position in the discharge region **201** of arc discharge chamber **20**. A typical diameter of interconnection wire **26a** is 0.9 mm, and a typical diameter of electrode shaft **31a** is 0.5 mm. In this specification, the interconnection wire **26a**, the lead-through wire **29a**, the main electrode shaft **31a** and the tungsten electrode coil **32a** are connected to the first access wire **14** so as to be powered, i.e., the inter connection wire **26a**, the lead-through wire **29a**, the main electrode shaft **31a** and the tungsten electrode coil **32a** collectively function as a first electrode.

[0036] Similarly, in Figure **2**, the chamber electrode interconnection wire **26b** is formed of niobium. The wire **26b** also has a thermal expansion characteristic that relatively closely matches that of the tube **21b** and that of a glass frit **27b**. In this embodiment, the interconnection wires **26a** and **26b** are formed of niobium, but the present invention is not limited to this material. The interconnection wires **26a** and **26b** may be formed of electrically-conductive cermet, or the like, which has a thermal expansion characteristic that relatively closely matches that of alumina. The chamber electrode interconnection wire **26b** is affixed by the glass frit **27b** to the inner surface of tube **21b** (and hermetically sealing that interconnection wire opening with wire **26b** passing therethrough). One end of molybdenum lead-through wire **29b**, which can withstand operation in the plasma, is connected to one end of interconnection wire **26b** by welding, and other end of lead-through-wire **29b** is connected to one end of a tungsten main electrode shaft, **31b**, by welding.

[0037] A tungsten electrode coil, **32b**, is integrated and mounted to the tip portion of the other end of the main electrode shaft **31b** by welding, so that electrode **33b** is configured by main electrode shaft **31b** and electrode coil **32b**. Lead-through wire **29b** serves to dispose electrode **33b** at a predetermined position in the discharge region **201** of arc discharge chamber **20**. A typical diameter of interconnection wire **26b** is also 0.9 mm, and a typical diameter of the main electrode shaft **31b** is again 0.5 mm. In this specification, the interconnection wire **26b**, the lead-through wire **29b**, the main electrode shaft **31b** and the tungsten electrode coil **32b** are connected to the second access wire **15** so as to be powered, i.e., the interconnection wire **26b**, the lead-through wire **29b**, the main electrode shaft **31b** and the tungsten electrode coil **32b** collectively function as a second electrode.

[0038] A further lamp structural consideration is the ratio of the length or distance "L" between the electrodes **33a** and **33b** of the arc chamber **20** (electrode separation distance) to the effective inner diameter "D" (or, alternatively, the effective inner radius) of the chamber wall structure **25** of the arc chamber **20** over that electrode separation distance L, i.e., the ratio of L/D. The electrode separation distance L crosses the diameter D substantially at right angles. In this

specification, "crossing at right angles" includes not only a case where the electrode separation distance L crosses the diameter D precisely at right angles, but also a case where the electrode separation distance L does not cross the diameter D precisely at right angles so long as a decrease of emission characteristic, which may result from crossing not precisely at right angles, causes no influence on a general lamp design. This ratio is a significant factor in choosing the arc chamber configuration along with the chamber total contained volume (which forms the discharge region **201**) insofar as the ratios of quantities of active materials contained in the chamber **20** to the volume of the chamber **20**. This aspect ratio of L to D influences the amount of light being radially emitted from the arc chamber **20**, the excited state distribution of active material atoms, the broadening of the material emission lines, etc.

[0039] In addition, smaller effective diameter D of the arc chamber **20** will reduce the self-absorption of strong radiating spectral lines of the radiating metals in arc chamber **20**. As seen from Figure **3**, the increase of self-absorption with increasing effective diameter D of the arc chamber **20** will reduce lamp efficacy. If a long lamp life is to be achieved, the arc chamber power wall loading must be limited to some maximum value (about 30 to 35 W/cm^2 for low wattage metal halide lamps with ceramic arc discharge chambers). At higher power loadings, typically, the chemical reactions of the active material salts with the arc chamber walls and the frit material become so severe that there is substantial difficulty in obtaining sufficient useful operating lives from such lamps.

[0040] The arc chamber electrode separation length L and the arc chamber effective diameter D (or radius) over that separation length L cannot be independently chosen. For smaller arc chamber effective diameters D, the arc chamber electrode separation length L has to be increased to reduce or eliminate the otherwise resulting increase of the wall loading of the arc chamber **20** by increasing the inner wall area. In maintaining a fixed wall loading value, the longer the arc chamber electrode separation length L, the smaller the arc chamber effective diameter D (or radius) can be. In the situation of holding the ratio of arc chamber electrode separation length L to arc chamber effective diameter D (or radius) fixed, the greater the wall loading value that can be accepted, the greater the resulting efficiency in generating light radiation by the metal halide discharge arc in the arc chamber **20** until that efficiency reaches a limiting value.

[0041] Now, refer to Figure **4**. Figure **4** shows a relationship between the lamp efficacy (LPW) and the ratio of the electrode separation distance L to the effective diameter D (L/D) for a typical lamp of the present invention. The lamp efficacy in a conventional high efficacy lamp is typically 95 lumens-per-watt (LPW). In a lamp of the present invention, when the electrode separation distance L and the diameter D satisfy the relationship of $L/D \geq 2$, a lamp efficacy equal to or higher than 95 LPW which is substantially the same as the conventional lamp efficacy can be obtained. Further, when the relationship of $L/D>4$ is satisfied, a high lamp efficacy which is greater than the conventional lamp efficacy by 20% or more can be obtained. Since the lamp efficacy of the lamp of the present invention is greater than the conventional lamp efficacy by 20% or more, the number of lamp devices can be reduced by 20% as compared with those used in a conventional lighting system.

[0042] More preferably, the electrode separation distance L and the diameter D satisfy the relationship of $7 \leq L/D \leq 9$. In this case, the highest lamp efficacy can be obtained. As seen from Figure **4**, when the relationship of $L/D>9$ is satisfied, the lamp efficacy decreases from the highest lamp efficacy. However, the lamp efficacy of the present invention is higher than the conventional lamp efficacy (95 LPW) so long as the electrode separation distance L and the diameter D satisfy the relationship of $9<L/D \leq 20$. If the electrode separation distance L and the diameter D satisfy the relationship of $L/D>20$, the electrode separation distance L is very large, or the diameter D is very small. In the case where the electrode separation distance L is very large, start and maintenance of discharge using a commonly-employed lighting circuit become difficult. In the case where the diameter D is very small, maintenance of discharge becomes difficult due to extinguishment of electrons at the wall of the chamber wall structure **25**. Thus, it is desirable that the electrode separation distance L and the diameter D satisfy the relationship of $L/D<20$.

[0043] A parameter for characterizing arc discharge lamps, termed normalized wall loading (watts/arc tube diameter), combines the effects of wall loading and radiation trapping phenomena into one combined measure thereof. Figure **5** shows a graph of the lamp efficacy (LPW) of the above-described arc chamber **20** using the normalized wall loading (watts/effective diameter (W/D)) as a parameter. As can be seen from Figure **5**, lamp efficacies can be increased with increasing arc chamber wall loading up to a maximum value and, thereafter, the efficacy more or less saturates. This indicates there is no further efficacy gain in either further increasing wall loadings or further reducing arc chamber diameters (i.e., effective diameter D), or combinations thereof leading to larger normalized wall loading parameter values. In the arc chambers characterized in Figure **5**, the optimum efficacy is obtained at normalized wall loading parameter values of around 30 to 44 watts/mm. Beyond these values, there are either diminishing returns or no gain in efficacy and, most likely, a reduced lamp operating life.

[0044] Arc chamber **20** can be configured with alternative geometrical shapes different from the configuration of Figures **1** and **2** as shown in the examples of Figures **6A** through **6G**. In each instance shown in Figures **1** and **2**, and in Figures **6A** through **6G**, a cross section view through the length axis of the arc chamber configuration is shown with the inner and outer wall surfaces being surfaces of revolution about the chamber length axis although this is not necessarily required. The effective diameter D of such inner surfaces can be found by determining the interior area of the cross section view between the electrodes, i.e. over the electrode separation length L, and dividing that area by L.

Other kinds of inner surfaces may require a more elaborate averaging procedure to determine an effective diameter therefor.

[0045] Figure **6A** shows an arc chamber where a cross section of the wall structure is an ellipse.

[0046] Figure **6B** shows an arc chamber having a cross section forming a right cylinder truncated such that the ends of the wall structure are flat.

[0047] Figure **6C** shows an arc chamber having a cross section such that the ends of the wall structure are hemispherical and the sides of the wall structure are concave.

[0048] Figure **6D** shows an arc chamber having a cross section forming a right cylinder truncated such that the ends of the wall structure are hemispherical.

[0049] Figure **6E** shows an arc chamber having a cross section such that the ends of the wall structure are hemispherical and the sides of the wall structure are elliptical.

[0050] Figure **6F** shows an arc chamber having a cross section forming a right cylinder truncated with smaller diameter flat ends joined to the cylinder with partial cones to provide a narrowing taper therebetween.

[0051] Figure **6G** shows an arc chamber having a cross section forming a right cylinder truncated with larger diameter flat ends joined to the cylinder with partial inverted cones to provide an outward flaring taper therebetween.

[0052] Many further alternative configurations are possible. Each configuration is desirable for different reasons. Thus, every alternative configuration has its advantages and disadvantages. That is, for specific active materials and other lamp characteristics, certain arc chamber configurations have more advantages than do others. According to any of the arc chamber configurations shown in Figures **6A** and **6F**, when an ionizable material provided to a discharge region of the present invention is used, and the electrode separation distance L and the diameter D satisfy the above relationship (i.e., L/D>4), an arc discharge metal halide lamp having a lamp efficacy higher than the conventional lamp efficacy is obtained.

[0053] Next, specific structures of a metal halide lamp of the present invention based on the structure shown in Figures **1** and **2** are described below.

(Embodiment 1)

[0054] In embodiment 1 of the present invention, the arc discharge chamber **20** is made from polycrystalline alumina to have a cavity length of about 36 mm in the contained discharge region **201**. The effective diameter D of the chamber wall structure **25** between electrodes **33a** and **33b** is about 4 mm. The electrode separation distance L of the electrodes **33a** and **33b** in the discharge region **201** contained in the chamber **20** is about 32 mm, so as to yield an arc length of the same value. The rated power of the lamp is nominally 150 W. The quantities of active materials provided in the discharge region **201** contained within arc discharge chamber **20** are 0.5 mg of Hg, 10 to 15 mg of the metal halides, praseodymium halide (PrI_3) and sodium halide (NaI), in a PrI_3:NaI molar ratio range of 1:3.5 to 1:10.5. In addition, xenon (Xe) gas was provided in the discharge region **201** at a pressure of about 330 mbar at room temperature as an ignition gas.

(Embodiment 2)

[0055] In embodiment **2** of the present invention, another metal halide (cerium iodide (CeI_3)) is added therein and an arc chamber of the same configuration having a shorter electrode separation distance L and a larger effective diameter D is used. In embodiment 2, the cavity length of the contained discharge region **201** in the arc discharge chamber **20** is about 28 mm. The effective diameter D of the chamber wall structure 25 between electrodes **33a** and **33b** is about 5 mm. The electrode separation distance L between the electrodes **33a** and **33b** in the chamber **20** is about 24 mm, so as to yield an arc length of the same value. The rated power of the lamp is again 150 W. The quantities of active materials provided in the discharge region **201** contained within arc discharge chamber **20** were 2.2 mg of Hg and 15 mg of the metal halides PrI_3, CeI_3 and NaI in alternative PrI_3:CeI_3:NaI molar ratios of 0.5:1:15.75, 0.88:1:19.69, or 2:1:31.5. Again, Xe gas was provided in this discharge region **201** at a pressure of about 330 mbar at room temperature as an ignition gas.

[0056] In embodiments 1 and 2, Xe is employed as an ignition gas, but the present invention is not limited thereto. The ignition gas is selected from a group consisting of xenon (Xe), argon (Ar), neon (Ne), and krypton (Kr).

[0057] Figure 7 shows relationships between CCT (K) changes and lamp power wattage (W) changes of typical combined PrI_3 and NaI active material lamps based on, or similar to, embodiment 1 of such lamps given just above for different halide active material molar ratios. In the legend, boxes □denote a result of an arc discharge metal halide lamp where the total amount of PrI_3 and NaI is 10 mg, and the molar ratio of PrI_3:NaI is 1:3.5; circles O denote a result of an arc discharge metal halide lamp where the total amount of PrI_3 and NaI is 10 mg, and the molar ratio of PrI_3:NaI is 1:7; and triangles Δ denote a result of an arc discharge metal halide lamp where the total amount of PrI_3 and NaI is 10 mg, and the molar ratio of PrI_3:NaI is 1:10.5. When the lamp power wattage (W) is reduced from their full rated

power (150 W) by limiting the electrical current therethrough, the corresponding CCT (K) values decrease. In arc discharge metal halide lamps having various molar ratios, the lamp power wattage was reduced from the full rated power (150 W) down to 50% (75 W) so as to dim the lamp. As a result of dimming of these arc discharge metal halide lamps, the change in CCT value in any of the lamps was considerably smaller compared with CCT value changes in existing lamps.

[0058] Figure **8** shows relationships between the lamp efficacy (LPW) changes and lamp power wattage (W) changes of typical combined PrI_3 and NaI active material lamps based on, or similar to, embodiment 1 of such lamps given just above for different halide active material molar ratios. When the lamp power wattage are dimmed from their full rated power (150 W) by limiting the electrical current therethrough while operating at line voltage, the lamp efficacy values decrease according to the decrease of the lamp power wattage. The arc discharge metal halide lamp of Figure 7 is used herein again. In arc discharge metal halide lamps having various molar ratios, the lamp power wattage was reduced from the full rated power (150 W) down to 50% (75 W) so as to dim the lamp. As a result of dimming of these arc discharge metal halide lamps, the change in lamp efficacy values in any of the lamps was substantially the same as those in existing lamps.

[0059] Figure **9** shows relationships between the lamp CRI changes and lamp power wattage (W) changes of typical combined PrI_3 and NaI active material lamps based on, or similar to, embodiment 1 of such lamps given just above for different halide active material molar ratios. When the lamp power wattage are dimmed from their full rated power (150 W) by limiting the electrical current therethrough while operating at line voltage, the lamp CRI values decrease according to the decrease of the lamp power wattage. The arc discharge metal halide lamp of Figure **7** is used herein again. In arc discharge metal halide lamps having various molar ratios, the lamp power wattage was reduced from the full rated power (150 W) down to 50% (75 W) so as to dim the lamp. As a result of dimming of these arc discharge metal halide lamps, the change in lamp CRI values in any of the lamps was considerably smaller compared with lamp CRI changes in existing lamps.

[0060] Figure **10** shows the relationship between the lamp efficacy and the mercury dose per unit volume of the region containing an active material used in an arc chamber of typical lamps of the present invention. For lamps operated at a specific lamp voltage, a relatively lower mercury dose per unit chamber volume is used in narrower and longer arc chambers such as the one used in embodiment 1 above, and a relatively higher mercury dose per unit volume is used in wider and shorter arc chambers such as the one used in embodiment 2 above. Lamps using a lower mercury dose per unit chamber volume have relatively higher lamp efficacy values when praseodymium halide and sodium halide are used as active materials.

[0061] In a lamp of the present invention, when the mercury dose per unit volume (mg/cm^3) was equal to or lower than about 16 mg/cm^3, a lamp efficacy equal to or higher than 95 LPW which is substantially the same as the conventional lamp efficacy was obtained. When the mercury dose per unit volume (mg/cm^3) was equal to or lower than about 4 mg/cm^3, a lamp efficacy higher than the conventional lamp efficacy by 20% was obtained. Since the lamp efficacy of the lamp of the present invention is greater than the conventional lamp efficacy by 20% or more, the number of lamp devices can be reduced by 20% as compared with those used in a conventional design of a lighting system, while maintaining the emission characteristics.

[0062] Next, Examples 1-8 which are different from above embodiments 1 and 2 will be described . For Examples 1-8, measurement results of various optical characteristics for the full rated power will be shown. For Examples 1-5, measurement results of various optical characteristics are shown for both the full rated power and the half rated power. Dimming of the lamps of Examples 1-5 were accomplished by limiting the electrical currents flowing therethrough while allowing the lamps to operate at line voltage.

EXAMPLES

(Example 1)

[0063] The quantities of active materials provided in the discharge region **201** of the arc discharge chamber **20** were 0.5 mg of Hg and 15 mg total of metal halides NaI and PrI_3 in a molar ratio of PrI_3:NaI=1:3.5. Xe gas was provided in the discharge region **201** at a pressure of about 330 mbar at room temperature. The volume of the discharge chamber **20** was 0.45 cm^3, the mercury dose per unit volume was about 1.1 mg/cm^3, and the arc length between the electrodes **33a** and **33b** (electrode separation distance L) was 32 mm. The effective diameter D of the chamber wall structure **25** was 4 mm. Wall loading was 31 W/cm^2 at 150 W. Lamp photometry results are shown in Table 1 below.

(Example 2)

[0064] The quantities of active materials provided in the discharge region **201** of the arc discharge chamber **20** were 0.5 mg of Hg and 10 mg total of metal halides NaI and PrI_3 in a molar ratio of PrI_3:NaI=1:3.5. Xe gas was provided in

the discharge region **201** at a pressure of about 330 mbar at room temperature. The volume of the discharge chamber **20** was 0.45 cm^3, the mercury dose per unit volume was about 1.1 mg/cm^3, and the arc length between the electrodes **33a** and **33b** (electrode separation distance L) was 32 mm. The effective diameter D of the chamber wall structure **25** was 4 mm. Wall loading was 31 W/cm^2 at 150 W. Lamp photometry results are shown in Table 1 below.

(Example 3)

[0065] The quantities of active materials provided in the discharge region **201** of the arc discharge chamber **20** were 0.5 mg of Hg and 10 mg total of metal halides NaI and PrI_3 in a molar ratio of PrI_3:NaI=1:7. Xe gas was provided in the discharge region **201** at a pressure of about 330 mbar at room temperature. The volume of the discharge chamber **20** was 0.45 cm^3, the mercury dose per unit volume was about 1.1 mg/cm^3, and the arc length between the electrodes **33a** and **33b** (electrode separation distance L) was 32 mm. The effective diameter D of the chamber wall structure **25** was 4 mm. Wall loading was 31 W/cm^2 at 150 W. Lamp photometry results are shown in Table 1 below.

(Example 4)

[0066] The quantities of active materials provided in the discharge region **201** of the arc discharge chamber **20** were 0.5 mg of Hg and 12.5 mg total of metal halides NaI and PrI_3 in a molar ratio of PrI_3:NaI=1:7. Xe gas was provided in the discharge region **201** at a pressure of about 330 mbar at room temperature. The volume of the discharge chamber **20** was 0.45 cm^3, the mercury dose per unit volume was about 1.1 mg/cm^3, and the arc length between the electrodes **33a** and **33b** (electrode separation distance L) was 32 mm. The effective diameter D of the chamber wall structure **25** was 4 mm. Wall loading was 31 W/cm^2 at 150 W. Lamp photometry results are shown in Table 1 below.

(Example 5)

[0067] The quantities of active materials provided in the discharge region **201** of the arc discharge chamber **20** were 0.5 mg of Hg and 10 mg total of metal halides NaI and PrI_3 in a molar ratio of PrI_3:NaI=1:10. Xe gas was provided in the discharge region **201** at a pressure of about 330 mbar at room temperature. The volume of the discharge chamber **20** was 0.45 cm^3, the mercury dose per unit volume was about 1.1 mg/cm^3, and the arc length between the electrodes **33a** and **33b** (electrode separation distance L) was **32** mm. The effective diameter D of the chamber wall structure **25** was 4 mm. Wall loading was 31 W/cm^2 at 150 W. Lamp photometry results are shown in Table 1 below.

(Example 6)

[0068] The quantities of active materials provided in the discharge region **201** of the arc discharge chamber **20** were 2.2 mg of Hg and 15 mg total of metal halides PrI_3, CeI_3 and NaI in a molar ratio of PrI_3:CeI_3:NaI=0.5:1:10.5. Xe gas was provided in the discharge region **201** at a pressure of about 330 mbar at room temperature. The volume of the discharge chamber **20** was 0.55 cm^3, the mercury dose per unit volume was about 4 mg/cm^3, and the arc length between the electrodes **33a** and **33b** (electrode separation distance L) was 24 mm. The effective diameter D of the chamber wall structure **25** was 6 mm. Wall loading was 31.3 W/cm^2 at 150 W. Lamp photometry results are shown in Table 1 below.

(Example 7)

[0069] The quantities of active materials provided in the discharge region **201** of the arc discharge chamber **20** were 2.2 mg of Hg and 15 mg total of metal halides PrI_3, CeI_3 and NaI in a molar ratio of PrI_3:CeI_3:NaI=0.8:1:19.69. Xe gas was provided in the discharge region **201** at a pressure of about 330 mbar at room temperature. The volume of the discharge chamber **20** was 0.55 cm^3, the mercury dose per unit volume was about 4 mg/cm^3, and the arc length between the electrodes **33a** and **33b** (electrode separation distance L) was 24 mm. The effective diameter D of the chamber wall structure **25** was 6 mm. Wall loading was 31.3 W/cm^2 at 150 W. Lamp photometry results are shown in Table 1 below.

(Example 8)

[0070] The quantities of active materials provided in the discharge region **201** of the arc discharge chamber **20** were 2.2 mg of Hg and 15 mg total of metal halides PrI_3, CeI_3 and NaI in a molar ratio of PrI_3:CeI_3:NaI=2:1:31.5. Xe gas was provided in the discharge region **201** at a pressure of about 330 mbar at room temperature. The volume of the discharge chamber **20** was 0.55 cm^3, the mercury dose per unit volume was about 4 mg/cm^3, and the arc length

between the electrodes **33a** and **33b** (electrode separation distance L) was 24 mm. The effective diameter D of the chamber wall structure **25** was 6 mm. Wall loading was 31.3 W/cm^2 at 150 W. Lamp photometry results are shown in Table 1 below.

[TABLE 1]

Photometry results of the lamps of Examples 1-5 for both the full rated power and the half rated power, and photometry results of the lamps of Examples 6-8 for the full rated power				
Sample lamp No.	Wattage (W)	LPW	CCT(K)	CRI
1	150	118	4904	73
1	75	56	4460	68
2	150	118	4976	74
2	75	60	4653	66
3	150	128	4144	69
3	75	58	4351	54
4	150	125	4380	69
4	75	59	4011	62
5	150	125	3693	65
5	75	67	3467	62
6	150	127	3718	66
7	150	124	4128	71
8	150	119	4002	73

[0071] In reducing the operating power of the lamps of above Examples 1-6 from the full rated power (150 W) to half (75 W), the emitted light remained substantially white without a greenish hue. Such color was satisfactory to the eye for general illumination uses and it was substantially impossible to discern any color or hue change under such dimmed conditions. Thus, the lamps of the present invention remain at the same CCT and are substantially constant in terms of hue throughout the dimming range. Furthermore, the lamps of the present invention have a higher lamp efficacy as compared with the lamp efficacy of conventional, commonly-employed lamps at the full rated power.

[0072] In above embodiments 1 and 2 and Examples 1-8, only examples where the rated power of the lamp is nominally 150 W have been described. However, according to the present invention, the rated power of the lamp is not limited to 150 W. The same effects can be obtained for other rated power values by simply changing chamber configurations (the shape of a chamber, the electrode separation distance L, the effectivediameter D, the molar ratio of ionizable materials, and the like). For example, the rated power is in the range of 70 W to 400 W, the amount of PrI_3 in the discharge region is preferably in the range of 0.5 mg/cm^3 to 50 mg/cm^3. When the amount of PrI_3 is smaller than 0.5 mg/cm^3, a contribution by Pr to emission becomes small, and as a result, a desired lamp efficacy cannot be obtained. When the amount of PrI_3 is larger than 50 mg/cm^3, it becomes difficult to obtain white color emission, and discharge becomes unstable.

[0073] Figure **11** is a block diagram showing an electronic ballast circuit **40** in a lamp of the present invention. The electronic ballast circuit **40** changes the lamp power (operation power) during operation of the lamp so as to dim the lamp. For example, the electronic ballast circuit **40** can reduce the lamp power from 100% to 50%. The electronic ballast circuit **40** is connected to an electrical power source **47**. The electrical power source **47** may be a 60 Hz AC power source. The electrical power source **47** supplies an alternating current at 60 Hz for a fixed voltage to the electronic ballast circuit **40**.

[0074] The electronic ballast circuit **40** includes a power factor correction and electromagnetic interference filter circuit section **41** connected to the electrical power source **47**, a power regulation circuit section (voltage-decreasing chopper section) **42**, a full-bridge circuit section (full-bridge inverter) **43**, an ignitor **44**, and a dimming control circuit section **46**.

[0075] The power factor correction and electromagnetic interference filter circuit section **41** receives electric power from the electrical power source **47**. The power factor correction and electromagnetic interference filter circuit section **41** converts the alternating polarity line voltage to a constant polarity voltage having a value significantly greater than the peak line voltage while maintaining a sinusoidal current that is in phase with the line voltage. The power factor

correction and electromagnetic interference filter circuit section 41 limits an electromagnetic emission during such a conversion process.

[0076] The power regulation circuit section (voltage-decreasing chopper section) **42** receives a sinusoidal current and a constant polarity voltage from the power factor correction and electromagnetic interference filter circuit section **41**. The power regulation circuit section **42** generates and outputs regulated, constant polarity voltage and current. Such a regulation is accomplished by the dimming control circuit section **46** connected to the power regulation circuit section **42**. The dimming control circuit section **46** uses a reference value set therein to regulate the received voltage value to a predetermined voltage value. The power regulation circuit section **42** also outputs a 100% voltage at the start of lamp operation in order to perform arc discharge.

[0077] The full-bridge circuit section (full-bridge inverter) **43** converts the constant voltage waveform output from the power regulation circuit section **42** to a low frequency square wave.

[0078] The ignitor **44** generates a start voltage pulse of 4 kV. Thereafter, the ignitor **44** supplies the low frequency square wave voltage output from the full-bridge inverter **43** to the lamp **45** connected to the ignitor **44** so as to cause arc discharge of the lamp **45**.

[0079] Figure **12** shows a circuit diagram of the electronic ballast circuit **40** of Figure **11**. In Figure **12**, like elements are indicated by like reference numerals used in Figure 11, and detailed descriptions thereof are omitted. The power factor correction and electromagnetic interference filter circuit section **41** and the full-bridge inverter **43** are the same as conventional ones, and therefore, detailed descriptions thereof are omitted.

[0080] The power regulation circuit section **42** includes a resistance **Rc** for detecting a current flowing through the lamp **45**.

[0081] The dimming control circuit section **46** includes an amplification section **1202**, a comparison section **1204** and a driving circuit **1206**. The dimming control circuit section **46** monitors a current flowing through the resistance **Rc** and converts a detected current to a voltage. The converted voltage is referred to as a feedback signal **1201**.

[0082] The amplification section **1202** includes a resistance **R1**, a resistance **R2**, a reference voltage $\mathbf{V_{ref}}$ and an amplifier **1203**. The feedback signal **1201** is input to the error amplifier **1203** via the resistance **R1**. The error amplifier **1203** amplifies the feedback signal **1201** based on the reference voltage $\mathbf{V_{ref}}$, and the resistance **R1** and the resistance **R2**. The electric current flowing through the lamp can be set to a desired value by changing the reference voltage $\mathbf{V_{ref}}$. In this manner, the lamp power is changed so as to accomplish dimming of the lamp.

[0083] The comparison section **1204** includes a comparator **1205**. The amplified feedback signal **1201** is input to the comparator **1205**. The comparator **1205** compares the feedback signal **1201** with a sawtooth wave so as to generate a switching pulse signal for switching the switch **1207** of the power regulation circuit section **42**.

[0084] The driving circuit **1206** adjusts the switching pulse signal to a predetermined voltage level and outputs the adjusted switching pulse signal to the switch **1207**. The power regulation circuit section **42** is On/Off controlled based on the switching pulse signal so as to provide the lamp with an electric current adjusted to a desired value.

[0085] The electronic ballast circuit **40** used for operation of the lamp is not limited to the structures of Figures **11** and **12**. The electronic ballast circuit **40** may have any structure so long as the lamp power (operation power) can be changed by controlling en electric current supplied to the lamp.

[0086] Although the present invention has been described with reference to the preferred embodiments above, those skilled in the art understand that various changes can be made to such embodiments without departing from the spirit and scope of the present invention.

[0087] Ametal halide lamp of the present invention includes: a discharge chamber having a chamber wall structure, a first electrode, and a second electrode; and an ionizable material contained in the discharge chamber. The ionizable material includes at least two types of halides including praseodymium halide and sodium halide. The diameter D of the chamber wall structure and the electrode separation distance L between first and second electrodes cross each other substantially at right angles, and satisfy the relationship of L/D>4. Thus, the lamp efficacy obtained in such a lamp of the present invention is higher than the conventional lamp efficacy. Furthermore, when the above conditions are satisfied, a high lamp efficacy and good color performance can be maintained even under dimming conditions.

[0088] Various other modifications will be apparent to and can be readily made by those skilled in the art without departing from the scope and spirit of this invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the description as set forth herein, but rather that the claims be broadly construed.

Claims

1. A metal halide lamp, comprising:

    a discharge chamber having a light-transmissive chamber wall structure which defines a discharge region, a first electrode, and a second electrode, the first and second electrodes being positioned opposite to each

other; and
an ionizable material contained in the discharge region, the ionizable material including mercury, rare gas, and at least two types of halides which includes praseodymium halide and sodium halide,

wherein a diameter D of the chamber wall structure and an electrode separation distance L between the first and second electrodes cross each other substantially at right angles, and satisfy the relationship of L/D>4.

2. A metal halide lamp according to claim 1, wherein the chamber wall structure is formed of polycrystalline alumina.

3. A metal halide lamp according to claim 1, wherein the praseodymium halide is praseodymium iodide (PrI_3), and the sodium halide is sodium iodide (NaI).

4. A metal halide lamp according to claim 1, wherein the chamber wall structure has a first end positioned at the first electrode side and a second end positioned at the second electrode side, and the first end and the second end are tapered.

5. A metal halide lamp according to claim 4, wherein the discharge chamber further includes a thermal shield which covers at least one of the first end and the second end.

6. A metal halide lamp according to claim 1, wherein the rare gas is selected from a group consisting of xenon (Xe), argon (Ar), neon (Ne), and krypton (Kr).

7. A metal halide lamp according to claim 1, wherein the diameter D and the electrode separation distance L satisfy the relationship of $7 \leq L/D \leq 9$.

8. A metal halide lamp according to claim 1, wherein the ratio of the amount of mercury to the volume of the discharge region is equal to or smaller than 4 mg/cm^3.

9. A metal halide lamp according to claim 1, wherein the ionizable material further includes cerium halide.

10. A metal halide lamp according to claim 1, further comprising:

a light-transmissive bulbous envelope; and
a base connected to the envelope, the base having a first access wire and a second access wire extending into the envelope,

wherein the discharge chamber is placed in the envelope, the first electrode is connected to the first access wire, and the second electrode is connected to the second access wire.

11. A metal halide lamp according to claim 2, wherein the praseodymium halide is praseodymium iodide (PrI_3), and the sodium halide is sodium iodide (NaI).

12. A metal halide lamp according to claim 7, wherein the praseodymium halide is praseodymium iodide (PrI_3), and the sodium halide is sodium iodide (NaI).

13. A metal halide lamp according to claim 8, wherein the praseodymium halide is praseodymium iodide (PrI_3), and the sodium halide is sodium iodide (NaI).

14. A lighting system, comprising a metal halide lamp and an operation circuit for allowing the metal halide lamp to operate,
the metal halide lamp including:

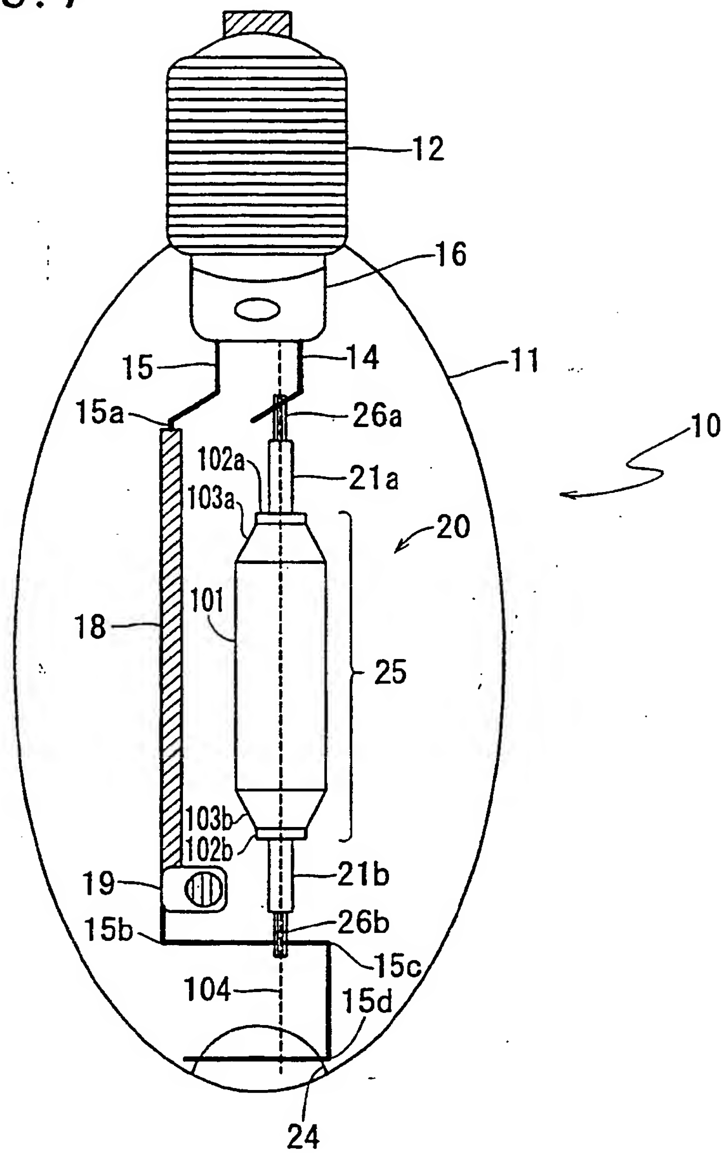
a discharge chamber having a light-transmissive chamber wall structure which defines a discharge region, a first electrode, and a second electrode, the first and second electrodes being positioned opposite to each other; and
an ionizable material contained in the discharge region, the ionizable material including mercury, rare gas, and at least two types of halides which includes praseodymium halide and sodium halide,

wherein a diameter D of the chamber wall structure and an electrode separation distance L between the first and second electrodes cross each other substantially at right angles, and satisfy the relationship of $L/D>4$, and

the operation circuit being constructed so as to supply the metal halide lamp with an electric voltage for allowing the metal halide lamp to start and discharge, and to supply the metal halide lamp with an electric current for adjusting an operation power of the metal halide lamp.

15. A lighting system according to claim 14, wherein the ratio of the amount of mercury to the volume of the discharge region is equal to or smaller than 4 mg/cm^3.

FIG. 1


12
16
15
14
11
15a
26a
10
102a
21a
103a
20
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18
25
103b
102b
19
21b
15b
26b
15c
104
15d
24

FIG. 2

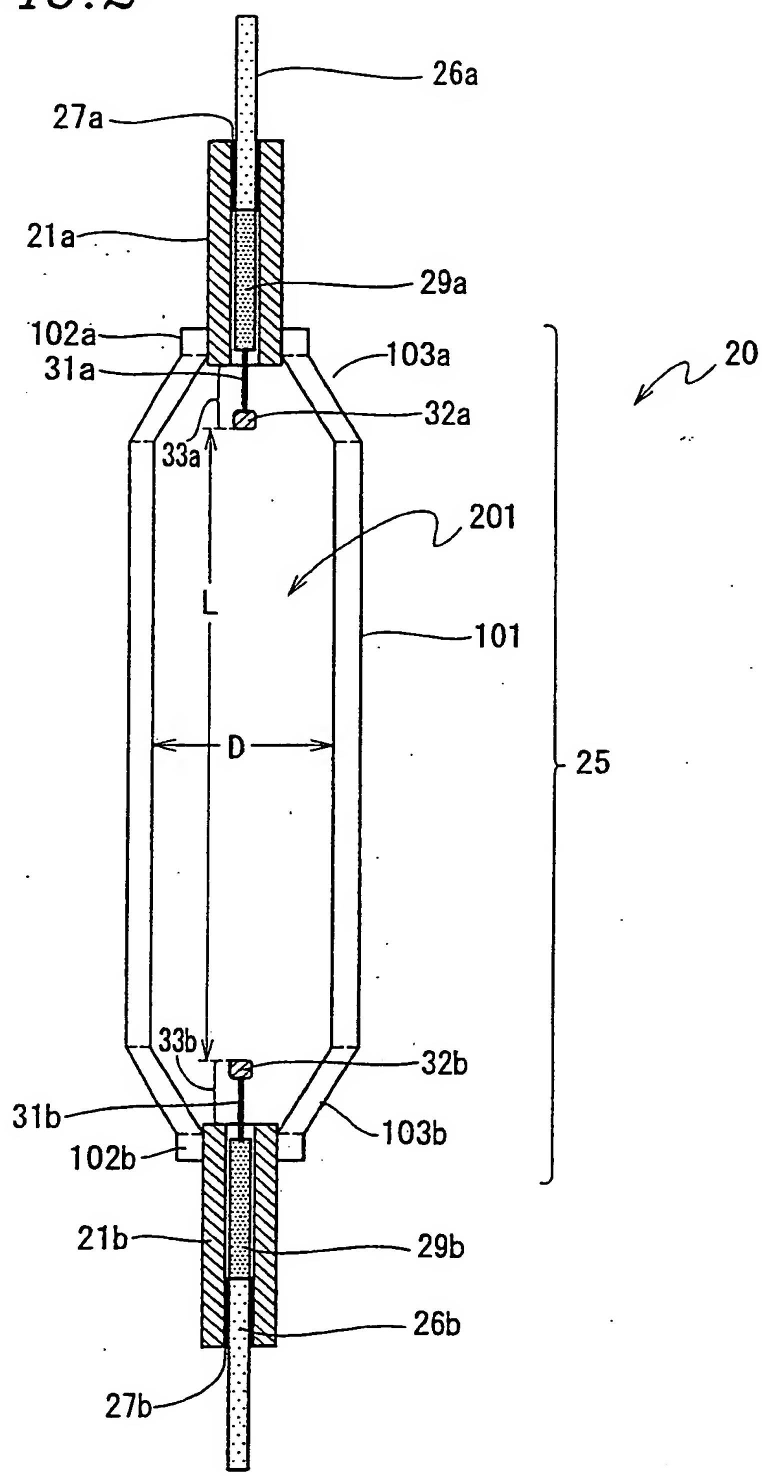

26a
27a
21a
29a
102a
31a
103a
20
32a
33a
201
L
101
D
25
33b
32b
31b
103b
102b
21b
29b
26b
27b

FIG. 3

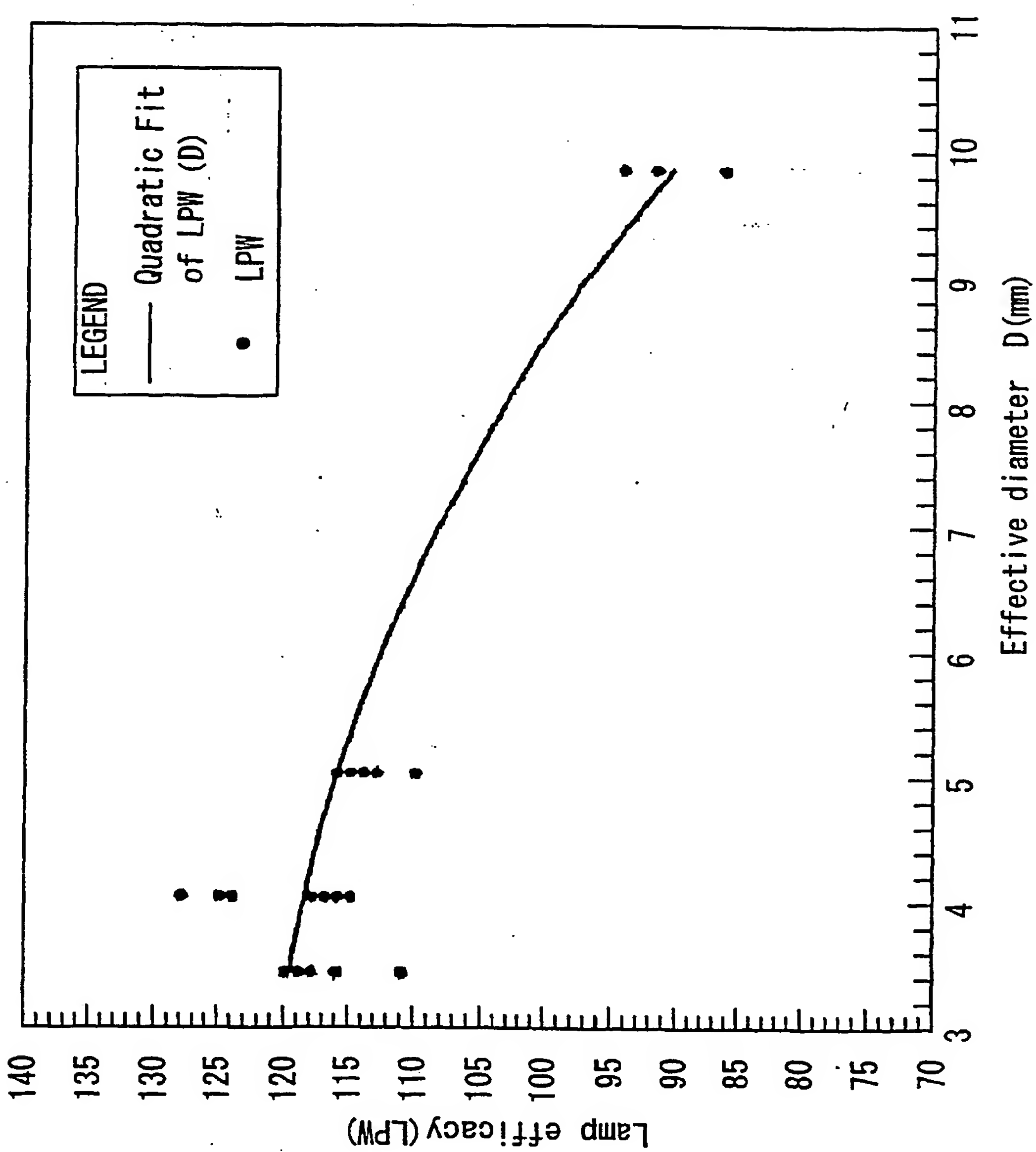

LEGEND
Quadratic Fit of LPW (D)
LPW
Effective diameter D(mm)
Lamp efficacy (LPW)
3
4
5
6
7
8
9
10
11
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140

FIG. 4

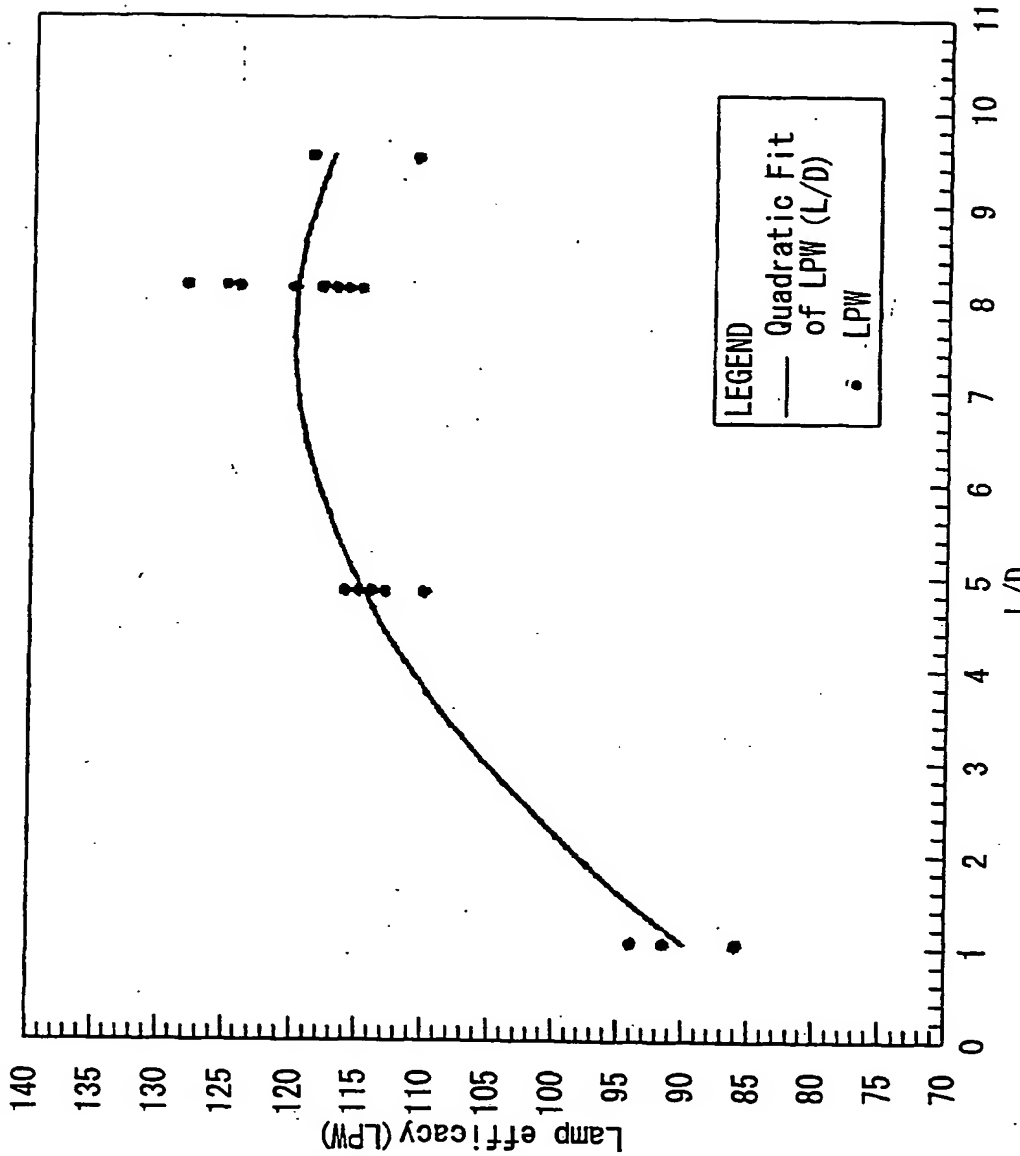

Lamp efficacy (LPW)
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
0
1
2
3
4
5
6
7
8
9
10
11
L/D
LEGEND
Quadratic Fit of LPW (L/D)
LPW

FIG.5

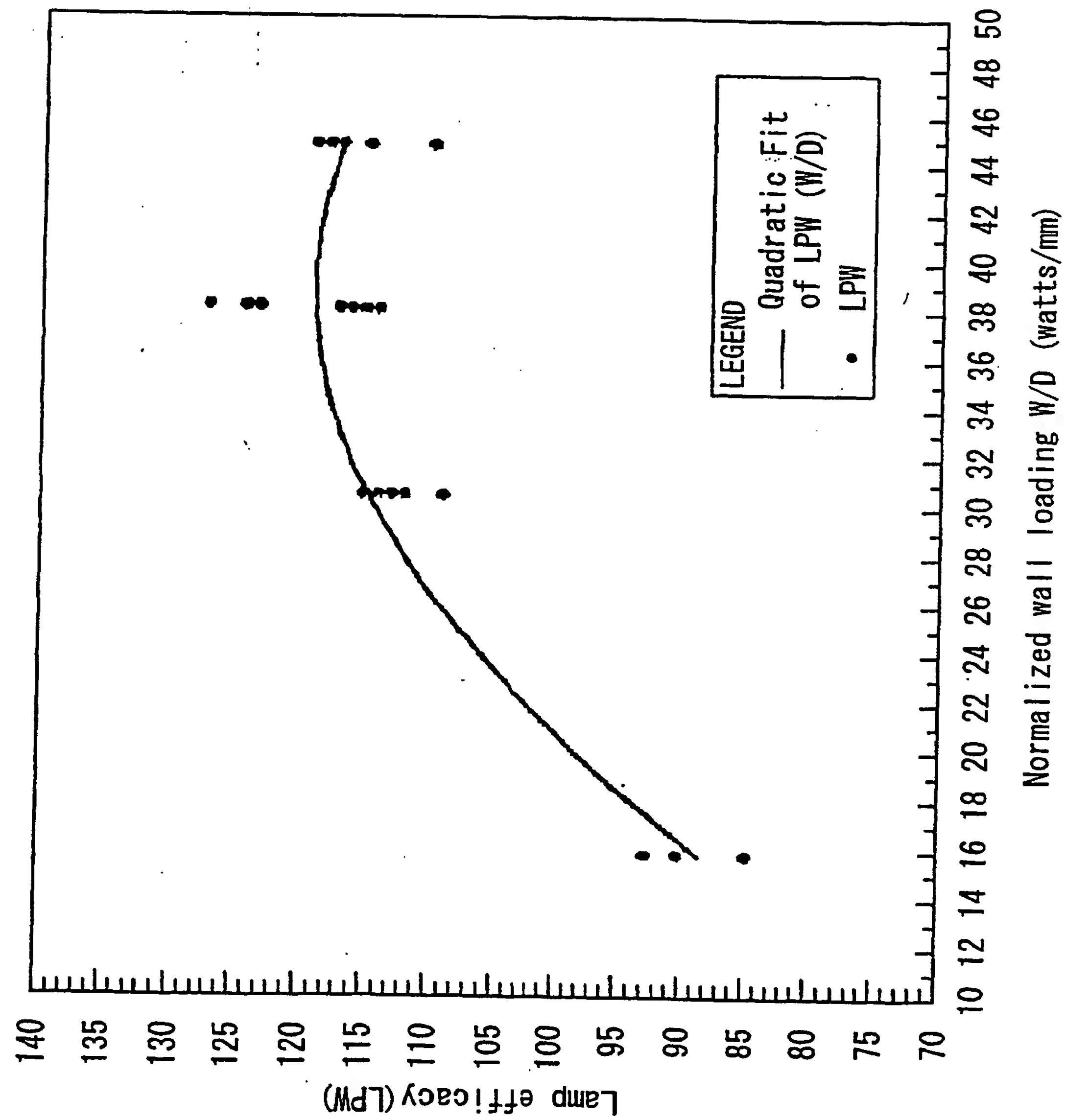

Lamp efficacy (LPW)
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
Normalized wall loading W/D (watts/mm)
10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
LEGEND
Quadratic Fit of LPW (W/D)
LPW

FIG. 6A

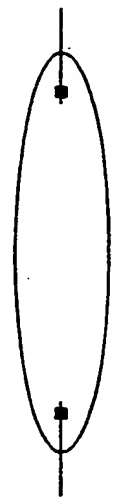


FIG. 6B

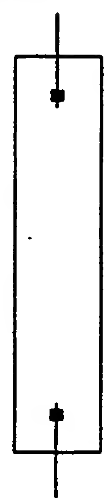


FIG. 6C

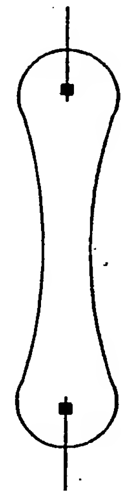


FIG. 6D

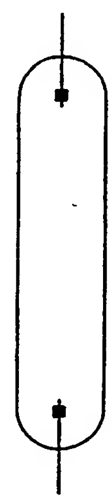


FIG. 6E

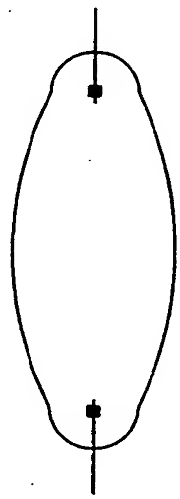


FIG. 6F

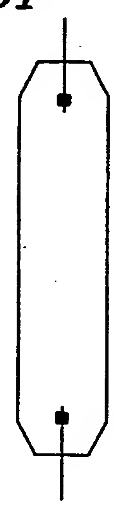


FIG. 6G

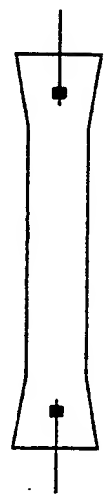
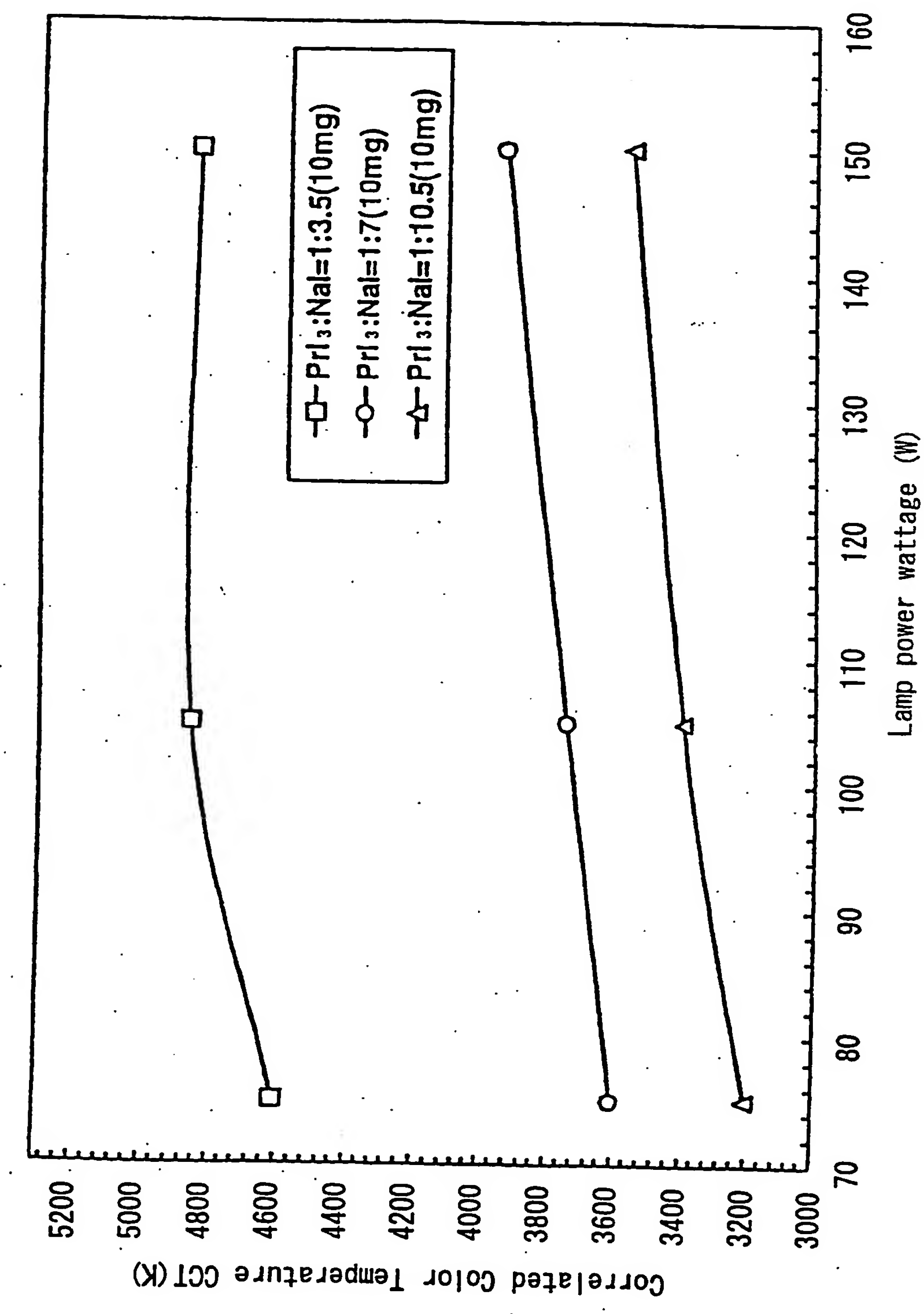


FIG. 7



PrI_3:NaI=1:3.5(10mg)
PrI_3:NaI=1:7(10mg)
PrI_3:NaI=1:10.5(10mg)
Correlated Color Temperature CCT (K)
Lamp power wattage (W)
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5200
70
80
90
100
110
120
130
140
150
160

FIG.8

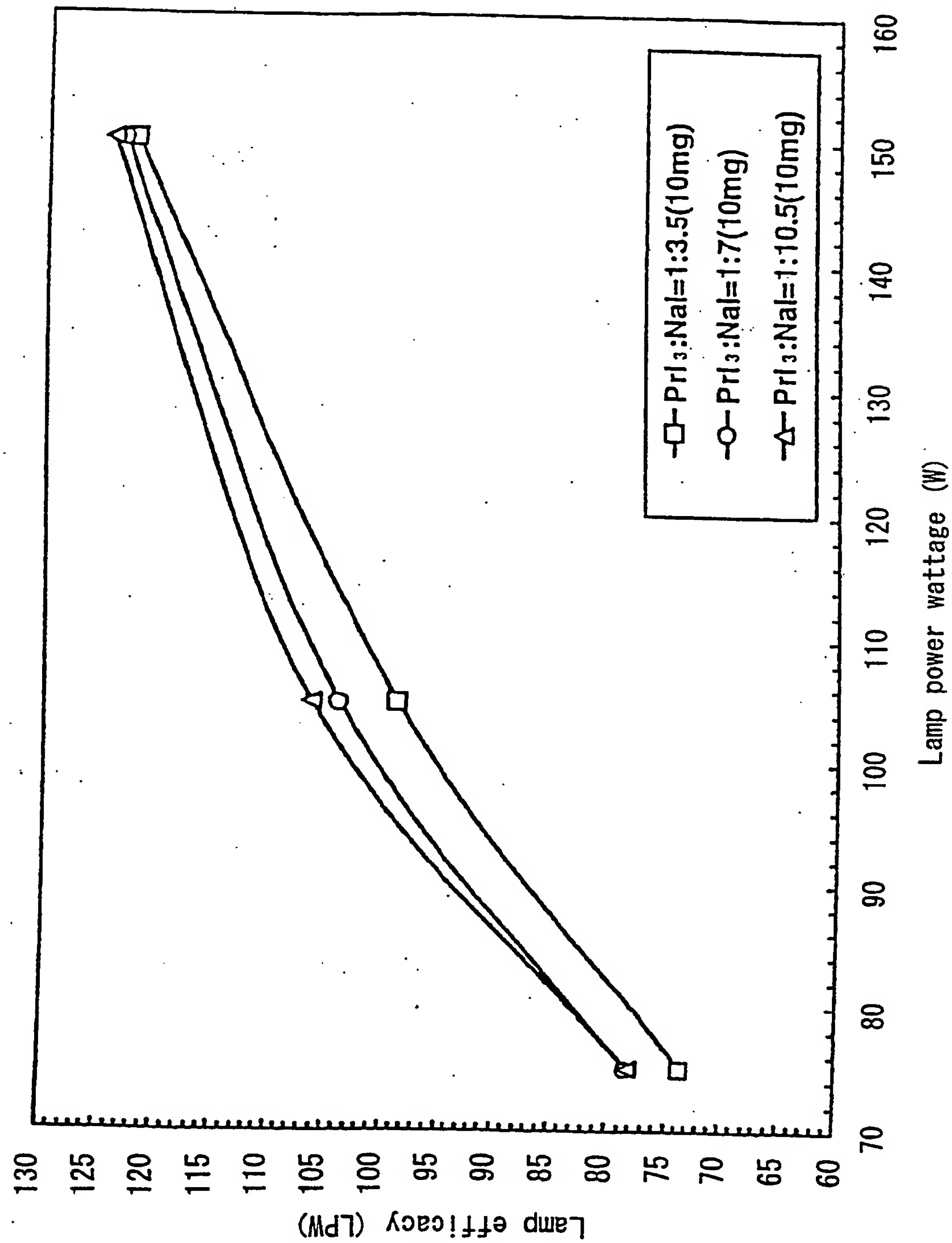

Lamp efficacy (LPW)
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
70
80
90
100
110
120
130
140
150
160
Lamp power wattage (W)
PrI3:NaI=1:3.5(10mg)
PrI3:NaI=1:7(10mg)
PrI3:NaI=1:10.5(10mg)

FIG. 9

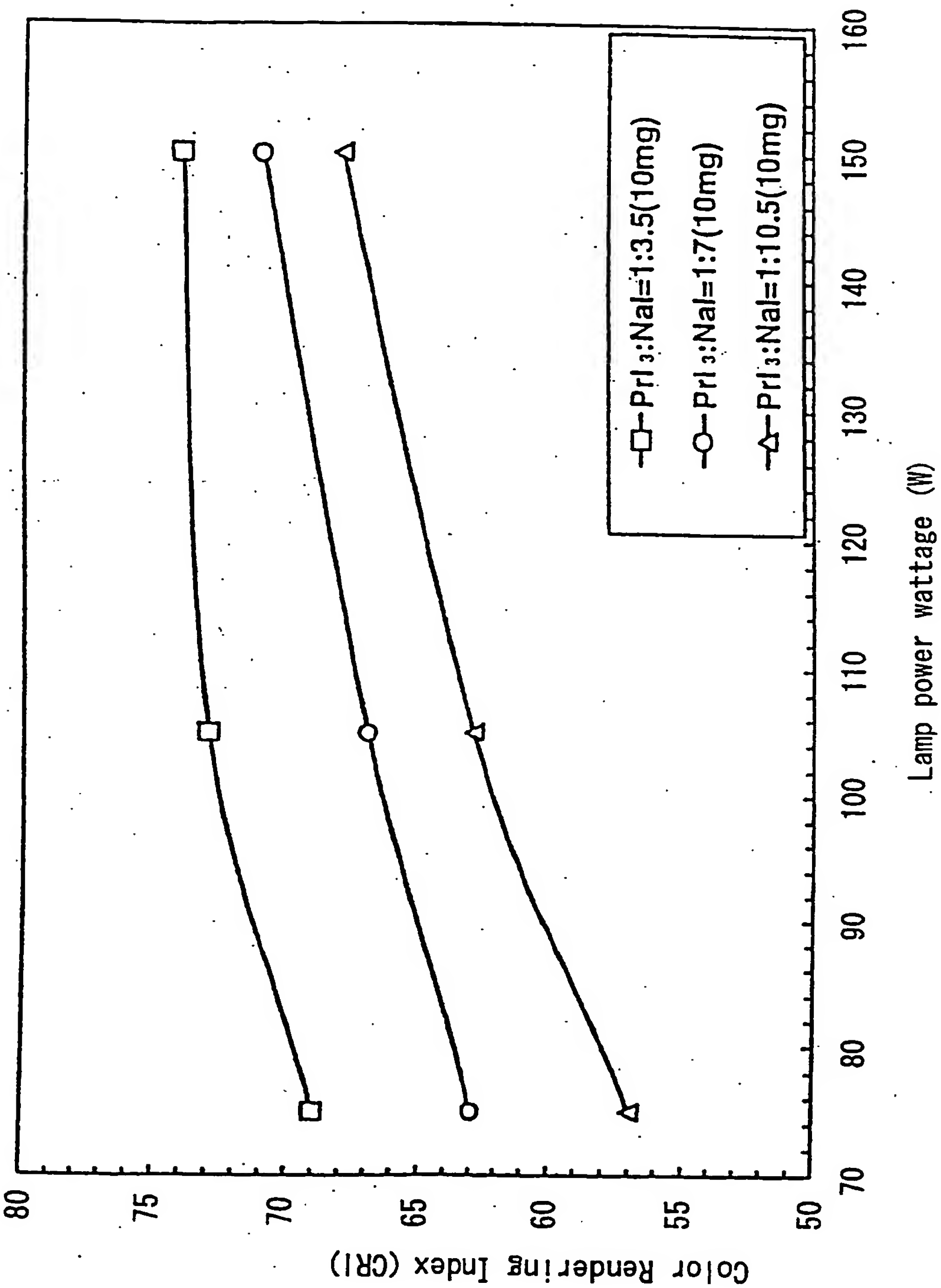

Color Rendering Index (CRI)
80
75
70
65
60
55
50
Lamp power wattage (W)
70
80
90
100
110
120
130
140
150
160
PrI₃:NaI=1:3.5(10mg)
PrI₃:NaI=1:7(10mg)
PrI₃:NaI=1:10.5(10mg)

FIG. 10

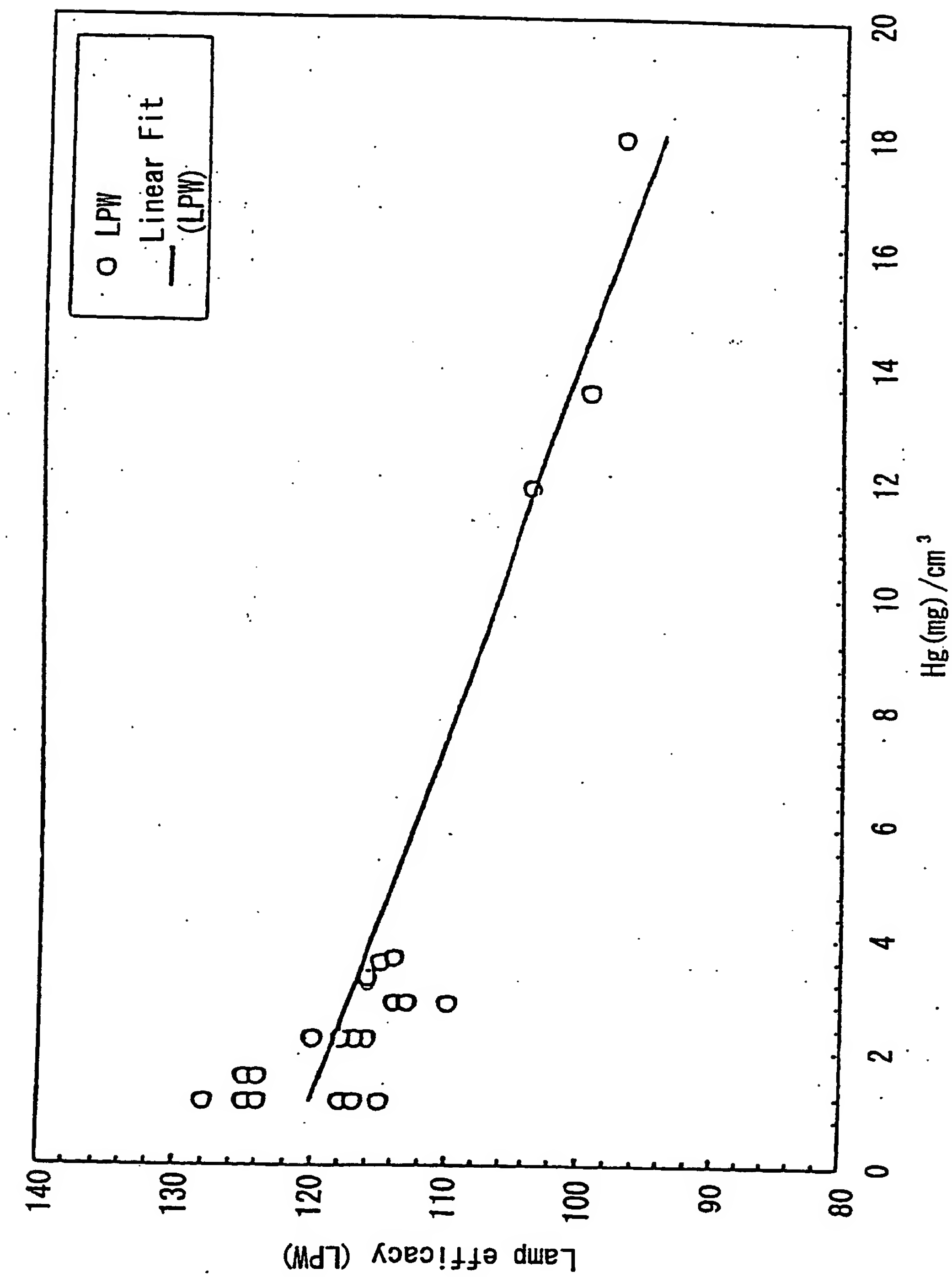
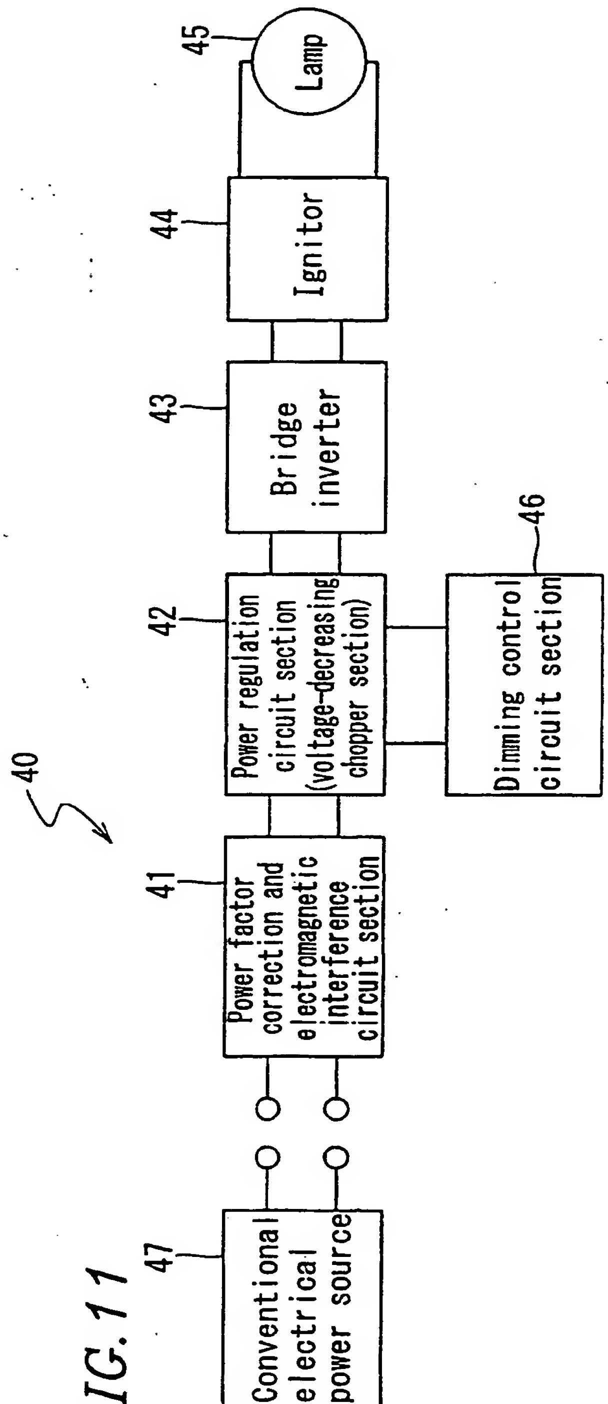

LPW
Linear Fit (LPW)
Lamp efficacy (LPW)
Hg (mg)/cm3
140
130
120
110
100
90
80
0
2
4
6
8
10
12
14
16
18
20

FIG. 11


40
41
Power factor correction and electromagnetic interference circuit section
42
Power regulation circuit section (voltage-decreasing chopper section)
43
Bridge inverter
44
Ignitor
45
Lamp
46
Dimming control circuit section
47
Conventional electrical power source

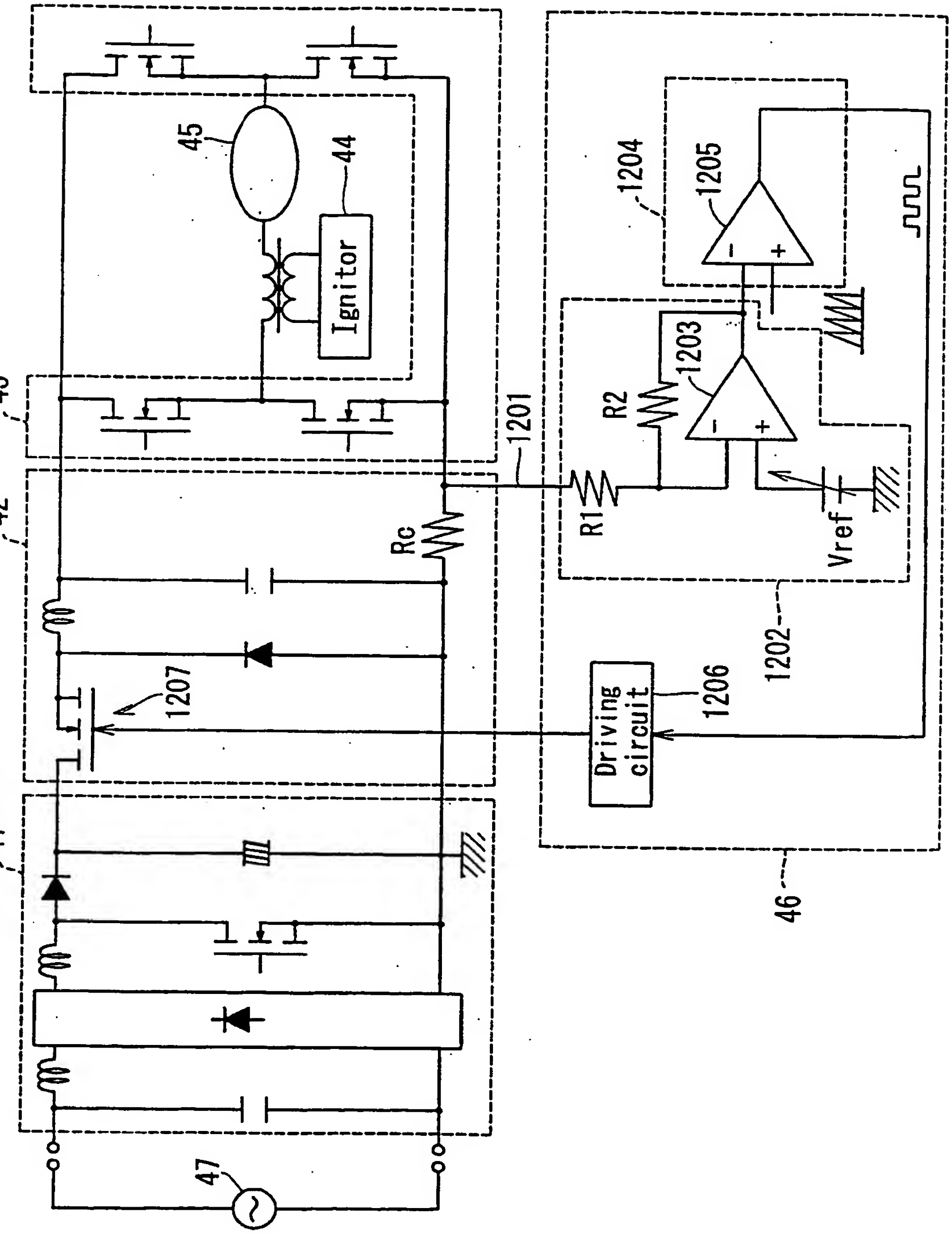

45
44
Ignitor
43
42
41
47
Rc
1207
1201
R1
R2
1203
1204
1205
Vref
1202
Driving circuit
1206
46

FIG.12